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DISPLACEMENT AND/OR ANGLE SENSOR WITH A MEANDER-SHAPED MEASURING WINDING

A process for measuring displacements and/or angles is described in Patent Application PCT/DE98/03,753. This process uses a measuring loop, in which a movable measuring head induces a voltage, which is divided by circuit devices in such a way that a displacement-dependent alternating voltage can be tapped at a measuring output. The division is preferably accomplished with the use of resistance networks or a distributed resistance. The characteristic curve of an arrangement such as this extends in only one direction over the measuring distance. In many applications, however, it is desirable to simulate nonlinear characteristics with a reversal of direction, e.g., a sine curve, over the displacement or angle.

The present invention pertains to a displacement or angle sensor, in which there is no need to divide the value; on the contrary, the induction loop is designed in such a way that the voltage induced in it depends on the position of the measuring head and can be tapped at the end of the measuring loop.

So that an induced, displacement-dependent voltage can be tapped from an induction loop, the integral over the alternating field passing through it must also be displacement-dependent. This is accomplished by having the measuring head generate a constant alternating field and by designing the measuring loop so that the component of the measuring head-generated flux permeating

the loop is proportional to the anticipated position-dependent signal.

In the displacement gauge disclosed in DT 2,511,681 A1, this is achieved by providing turns, the number of which increases with the distance from the zero point, on a surface permeated by the flux; in addition, the individual turns run at an angle into the surface. The use of a measuring loop with several turns suffers from the disadvantage that, when a relatively large number of turns is required, the winding becomes very wide, especially when the design includes a printed circuit, as is preferably done for reasons of economy and production efficiency. So that a continuous increase in the measuring voltage with increasing position is achieved, another turn must be provided at a distance as close as possible in value to the width of the measuring core. The measuring core must extend around one side of the coil in such a way that the flux passes through all the turns. Especially in cases of long measurement lengths, this can lead to a situation in which the measuring head and the measuring loop are relatively large, which has unfavorable effects both on costs and on the range of possible applications. Although it is possible to allow the turns which pass through the area of the air gap to extend at a slant, this leads to the disadvantage that the measurement result is strongly influenced by lateral displacements of the measuring head. In addition, it is difficult to adapt the pitch of the turn to the insufficiently linear course of the inducing magnetic field.

Another disadvantage of long measurement lengths is based on the distributed capacitance and inductance of the measuring winding, which, as a result, has a relatively low resonant frequency. Operation in the range of the resonant frequency or above would cause difficult-to-correct measurement errors.

These disadvantages can be eliminated by providing the measuring loop

with only one or with relatively few turns, which have the form of a meander. The meander has the same pitch over the entire measurement distance, but the width of the individual segments changes with the position in the measurement direction. The segments of the meander which project into the area of the measuring core are permeated by the magnetic field, whereas the other parts remain outside the magnetic field. When the ratio of the width of the meander segments which project into the core area to the pitch of the meander is proportional to the desired characteristic curve, the characteristic curve thus obtained approximates the desired characteristic curve. The advantage of this design is that it is possible to provide almost any desired number of turn segments crosswise to the measuring direction without causing an extreme increase in the width of the measuring coil or high inductance and high distributed capacitance of the measuring winding. This means that a narrow, short measuring core can be used. If a sufficient number of turns is present, it is possible to arrange the winding perpendicular to the measuring direction. As a result, the dependence on the course of the magnetic field crosswise to the measuring direction is considerably reduced.

Additional advantages and features of the invention can be derived from the following description and from the drawings:

– Figure 1 shows a schematic diagram of an embodiment of a sensor according to the invention;

– Figure 2 shows a schematic diagram of the voltage which can be tapped from the sensor illustrated in Figure 1 and of the magnetic induction;

– Figure 3 shows a schematic diagram of the induction occurring in the sensor shown in Figure 1;

– Figure 4 shows a different embodiment of an inductive sensor making use

of the invention; and

– Figure 5 shows a schematic diagram of an exemplary embodiment of a sensor.

Figure 5 shows an arrangement consisting of a core *31* with an air gap, in which a printed-circuit board *30* is present. A coil, through which current passes, generates an alternating field in the core, which pemeates the printed-circuit board *30*. The broken lines represent lines of equal induction. The diagrams next to and below these lines show the course of the induction in the direction of motion of the measuring head ($x$ direction) and crosswise to that (the $y$ direction). The physical circumstances make it impossible to arrive at a perfectly linear course. In contrast, it is possible to achieve a curve with good symmetry in the $x$ direction but not in the $y$ direction. To avoid sensitivity to lateral displacements ($y$ direction), the induction loop is designed so that it consists of conducting tracks *32* which extend in the direction of motion of the measuring core and also perpendicular to the direction of motion; they thus form rectangles, which project deeply into the air gap of the measuring core and thus absorb practically all of the magnetic flux in this area.

Figure 1 shows a design of this type. On the printed-circuit board *1* is a meander-shaped conducting track *2*, one end of which is connected to an electrical connecting terminal *4* by the conducting track *3*, whereas the other end is connected to connecting terminal *5*. The measuring core *6* has a winding *7*, through which an alternating current flows. The production of this alternating current is not described in detail here. It can be derived from, for example, DE 197-57,689.3-52 and from PCT/DE98/03,753, to which reference is made here.

Via the measuring core *6*, the current $I_V$ in the primary loop *10* induces a voltage in the winding *7*, which, along with a capacitor *11*, forms a resonant circuit. The excitation current, however, can also be generated elsewhere, e.g., by direct feed. The limbs of the core encompass the printed-circuit board *1*, so that the magnetic flux of the measuring core permeates the measuring loop where it projects into the core area (shown on the right). The pitch of this meander corresponds to the magnetically effective width of the measuring core *6* or a whole-number fraction thereof. Between the connecting terminals *4* and *5*, a voltage $U_{m1}$ is thus obtained as a function of the position of the measuring core, as shown in Figure 2. For the sake of simplification, it is assumed that the field extends only over the width of the measuring core and remains uniform there over the entire width. The voltage $U_{m1}$, which starts at 0 at the beginning of the measurement distance, increases in a linear manner by an amount of $1/n$ as the first, narrow segment of the meander extends into the core; the voltage then remains constant until the next segment is reached. At the end of the distance, the measuring loop occupies the entire field of the measuring core and thus provides full voltage.

In practice, the transition between the individual segments is not quite the same as illustrated in Figure 2, in which the magnetic flux is assumed to proceed as illustrated in Figure 3; instead, the field changes as illustrated in Figure 5. Because of unavoidable stray fields, the magnetic flux will also emerge laterally into the edge areas. This leads to the course shown in broken line in Figure 3. The solid line represents the idealized course, the broken line the actual course. As a result, the characteristic curve shown in Figure 2 becomes "blurred", which leads to an approximation to a continuous course or, in the example above, to a linear course. In addition, a suffi-

ciently close approximation of the characteristic to the desired course can also be achieved by designing the air gap and/or the cross section of the core in the air gap in an appropriate manner.

A further improvement is obtained by the use of a second measuring loop, e.g., on the rear surface of the printed-circuit board *1*. When this forms a meander which is offset by half the pitch and the output signal is formed from both measuring loops, the number of transitions is doubled.

In Figure 1, a conducting track *9* of this type is shown in broken line. It is connected at one end to the common connecting terminal *4* via the conducting track *3*; at the other end, it is connected to a test connector *8*. In correspondence with the flux permeating the conductor loops *3*, *9*, the voltage $U_{m2}$ is induced, as shown in Figure 2. From the difference between the two voltages $U_{m1}$ and $U_{m2}$, the voltage $U_m$ is formed, which has twice the number of transitions and twice the output voltage. The error associated with the transitions is thus cut in half. The same result is obtained when the two measuring loops are connected in series. In this case, the pitches of the two measuring loops must be the same.

Further improvement in the course of the curve can be obtained by designing the meander with a narrower pitch, in which case the effective width of the core is a whole-number multiple of the pitch of the meander.

In practice, errors occur as a result of temperature effects and lateral displacements of the measuring core. These errors can be avoided almost completely by using the ratio between a reference voltage, which represents all of the flux permeating the measuring core, and the measuring voltage at the measuring loop instead of the absolute value of the measurement voltage. Here it is a logical next step to provide another measuring loop, which is formed

in Figure 1 from a feed line *3* and a conducting track *13*, which leads to a connecting terminal *14*. While the measuring head is also contributing to the induction in the measuring loop, all of its flux permeates this additional loop regardless of the position of the head. The voltage available at the connecting terminal of this loop serves as a reference value for the total voltage induced by the measuring core.

In this measurement process, the techniques described in DE 197-57,689.3-52 and PCT/DE98/03,753 can be used concomitantly, to the entire content of which reference is made here and which are included in the present application:

— measuring core with a resonant coil;

— adaptation to oscillator impedance with transformer;

— use of the oscillator as the frequency-determining component of an oscillator circuit;

— ratio measurement with a reference winding;

— compensation for voltage not induced as a function of displacement.

The method of the meander-shaped induction loop can, of course, also be combined with a distributed resistance so that, for example, the sensor can be checked to see that it is functioning properly or so that additional control data can be obtained. It is possible to generate, for example, a curve of reference input values versus the displacement measured with the resistance element, an additional end-point signal, or the like. It is advantageous here that it is also possible to provide pitches in different directions over the entire distance, which is difficult to achieve with a distributed resistance.

Neither the measuring distance nor the measuring process using a resistance element is limited to straight stretches. The arrangement can also be

easily used for curves. These are preferably arcs of a circle, such those which occur when angles are measured.

Because the area ratio of the meander can be varied over the distance in any way desired, it is possible to generate any desired function over the measuring distance, as long as the pitch does not exceed a value predetermined by the width of the core. The maximum possible pitch is thus $U_{max}/b$, where $U_{max}$ is the maximum obtainable measurement voltage and $b$ is the width of the measuring core.

This is advantageous especially in applications where angles are measured over 360°C without any limitation on the angle. In this case, it is necessary to represent two functions in order to arrive at a clear correlation over the complete angular range. Known designs such as resolvers use an output signal in the form of a sine curve and additional signal in the form of a cosine curve. From the ratio of the two output voltages to each other, it is possible to calculate the angles uniquely anywhere in the rotational range. This process is not limited to a sine function.

Figure 4 shows a schematic diagram of an angle sensor for measuring angles over a range of 360°. On a rotatably supported shaft *17*, a measuring core *16* is mounted by a holder *16a* in such a way that a stationary, ring-shaped printed-circuit board *15*, which is concentric to the shaft, lies in the air gap of the measuring core *16*. When the shaft rotates, the measuring core *16* passes over the conducting tracks *18, 19*. The two conducting tracks *18, 19* are applied to opposite sides of the printed-circuit board *15*. Both have the same geometry but are offset 90° from each other. The conducting track *18* is shown on the top. It is divided into two halves, and in the middle it is connected by a conducting track *27*, which forms a circle around the conducting

track *18* and extends to the connecting terminal *23*, to the electrical reference point of the evaluation circuit *28*. On the side opposite the connecting terminals *21*, *22*, *23*, *24*, the conducting tracks *18* and *27* are connected electrically to each other by a contact point *27a*. The measurement signal is tapped at the two other connecting terminals *21*, *22* and also sent to the evaluation circuit. The conducting track *18* is designed in such a way that each of the two conducting tracks *27*, *18* forms a loop. Some, all, or none of the magnetic flux of the measuring core premeates this loop as a function of the angular position. A voltage is induced accordingly. The voltages at the connecting terminals *21*, *22* have a course which approximates a sine curve over 180°. The corresponding measuring loops on the rear (connecting terminals *21a*, *23a*, *24a*, *22a*) provide a sine curve offset by 90°, which corresponds to a cosine function. Appropriate evaluation in a circuit (not described in detail) then leads to a clear identification of the angle.

To obtain an exact fit to a sine curve or some other curve intended for evaluation, a suitably finer grid and/or an appropriately shaped measuring core and/or electronic linearization can be provided. For electronic linearization, a continuously rising measurement value is required, which is achieved by the use of a sufficiently fine grid and/or a suitably shaped measuring core.